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TITLE OF THE INVENTION

Solvent Extraction Process

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CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of copending provisional application serial
number 60/408,169, filed on September 3, 2002.

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FIELD OF THE INVENTION

This invention relates to a solvent extraction process for the recovery of metals
from aqueous solutions.

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BACKGROUND OF THE INVENTION

Solvent extraction is a widely used technology for the recovery of metals from
aqueous solutions containing the metals.

One of the more common staging configurations in metal recovery is two
20 extraction stages in combination with two strip stages for a total of four stages.

SUMMARY OF THE INVENTION

It has now been discovered that a staging arrangement employing three
countercurrent extraction stages with one strip stage is more effective for the recovery

of metal than the currently used staging arrangement of two extraction stages and two strip stages.

This new staging arrangement gives both higher metal recovery and more effective use of the organic phase and the metal extraction reagents present therein
5 when the staging arrangements are compared under the exact same conditions.

Moreover, the present invention does not increase capital costs since the total number of stages and the size of the plants are exactly the same in both staging arrangements.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a known staging arrangement in which two extraction stages are present in combination with two stripping stages.

Figure 2 shows the staging arrangement of the invention in which three extraction stages are present in combination with one strip stage.

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DETAILED DESCRIPTION OF THE INVENTION

Other than in the operating examples, or where otherwise indicated, all numbers expressing quantities of ingredients or reaction conditions used herein are to be understood as modified in all instances by the term "about".

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It should be noted that the present invention is not dependent on the particular metals present in the electrolyte solutions from which the metals are to be extracted. Also, different leach solutions can be used with respect to the metal ores. For example, nickel ores are typically leached with ammonia, extracted from the ammonia solutions, and stripped with acid to form an aqueous acidic electrolyte solution used in
25 an electrowinning step.

The solvent extraction process (SX process) for extracting metals such as copper typically involves the following steps, (plus a wash stage), which result in electrolyte solutions used in electrowinning copper metal. Other processes that include solvent extraction and stripping can be employed in accordance with the invention with other metals such as nickel, zinc and the like to produce an electrolyte from which their respective metals are electrowon:

1. Aqueous acid leaching of copper ore using a strong acid to form an aqueous acid leach solution containing copper ions and often relatively small quantities of other metal ions. The aqueous leach acid solution dissolves salts of copper and other metals if present as it is contacted with the ore, e.g. as it trickles through the ore. The metal values are usually leached with aqueous sulfuric acid, producing a leach solution having a pH of 0.9 to 2.0.
2. The copper-pregnant aqueous acid leach solution is mixed in tanks with an oxime extraction reagent which is dissolved in a water-immiscible organic solvent, e.g., a kerosene or other hydrocarbons. The reagent includes the oxime extractant which selectively forms a metal-extractant complex with the copper ions in preference to ions of other metals. The step of forming the complex is called the extraction or loading stage of the solvent extraction process. The oxime extractants used in this step are typically oxime extractants of the hydroxyl aryl ketone oxime or hydroxy aryl aldoxime type, or a mixture thereof. Alkylated aryl hydroxyoximes such as alkylated acetophenone oximes and/or alkylated salicylaldoximes can be used e.g. 5-nonyl-2-hydroxy-acetophenone oxime and/or 5-nonyl-salicylaldoxime.

3. The outlet of the mixer tank can continuously feed to a large settling tank or equivalent equipment, where the organic solvent (organic phase), now containing the copper-extractant complex in solution, is separated from the partially depleted aqueous acid leach solution (aqueous phase). This part of the process is called phase separation. However, the tanks used in step 2 can be mixer/settler tanks so that step 3 is not required.
4. After extraction, the partially depleted aqueous acid leach solution (raffinate) is either recycled for further leaching, or recycled with a bleed, or discharged.
5. The loaded organic phase containing the dissolved copper-extractant complex is fed to another mixer tank, preferably a stripper/settler tank, where it is mixed with an aqueous strip solution of more concentrated sulfuric acid. The highly acid strip solution breaks apart the copper-extractant complex and permits the purified copper to pass and concentrate in the strip aqueous phase. The process of breaking the copper-extractant complex is called the stripping stage.
6. As in the extraction process described above (steps 2 and 3), the mixture of stripped organic phase and copper pregnant aqueous acid strip solution can be fed to another settler tank for phase separation, or to another type of solvent extraction equipment that replaces the traditional stripper/settler tank. However, phase separation preferably takes place in the stripper/settler tank in step 5.
7. From the stripper/settler tank, the regenerated stripped organic phase is recycled to the extraction mixer to begin extraction again, and the copper is recovered from the strip aqueous phase, customarily by feeding the strip

aqueous phase to an electrowinning tankhouse, where the copper metal values are deposited on plates by a process of electrodeposition.

8. After recovering the copper values from the aqueous solution by electrodeposition, the solution, known as spent electrolyte, is returned to the stripping mixer to begin stripping again.

In the known process, set forth schematically in Figure 1, Leach Solution from step 1 above enters Extraction Stage 1 where it is mixed with Organic (the water-immiscible organic solvent containing the oxime extraction reagent) from Extraction Stage 2. Loaded Organic (which is the organic solvent containing the copper-extractant complex in solution) exits Extraction Stage 1 and is sent to Strip Stage 1, where it is contacted with Electrolyte (aqueous acid strip solution) from Strip Stage 2. Pregnant electrolyte (containing the copper) is removed for use in electrowinning the copper. Organic (containing the oxime extraction reagent and remaining copper-extractant complex) exits Strip Stage 1 and enters Strip Stage 2, where it is contacted with Barren Electrolyte (strip electrolyte) for further stripping of copper from the remaining copper-extractant complex. Stripped Organic containing the oxime extractant is sent to Extraction Stage 2 where Aqueous (leach solution still containing some copper in solution) from Extraction Stage 1 is further extracted. Aqueous Raffinate (depleted aqueous acid leach solution) is removed from Extraction Stage 2.

In the process of the present invention, set forth schematically in Figure 2, Leach Solution enters Extraction Stage 1, where it is mixed with Organic from Extraction Stage 2. Loaded Organic exits Extraction Stage 1 and enters the Strip Stage where it is contacted with Barren Electrolyte. Pregnant Electrolyte exits the Strip Stage for further processing by electrowinning. Stripped Organic leaves the Strip Stage and enters Extraction Stage 3, where it is contacted with Aqueous

(partially extracted leach solution) from Extraction Stage 2. Aqueous Raffinate is removed from Extraction Stage 3. Organic from Extraction Stage 3 is sent to Extraction Stage 2, where it is contacted with Aqueous from Extraction Stage 1.

In the circuit configuration of the invention, it is to be understood that the circuit configuration shown in Figure 2 can be used in one or more trains, depending on the size of the plant. Also, the circuit configuration shown in Figure 2 can be used with one or more wash stages, preferably a single wash stage.

The invention will be illustrated but not limited by the following examples.

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EXAMPLES

Example 1

This example compares a copper solvent extraction circuit having 2 extraction stages and 2 stripping stages (2E, 2S) with a copper solvent extraction circuit having 3 extraction stages and 1 strip stage (3E, 1S). An extraction isotherm was generated using an organic solution 0.296 molar in 5-nonyl-2-hydroxyacetophenone oxime (ketoxime) and 0.0964 molar in 5-nonylsalicylaldoxime (aldoxime) in a hydrocarbon diluent. The aqueous copper leach solution contained 6.36 g/l Cu and 150 g/l sulfate ion as sodium sulfate at a pH of 1.67. The above organic solution was first contacted several times with an aqueous solution having about 39 g/l Cu and 168 g/l sulfuric acid to obtain a preliminary stripped organic phase containing 1.37 g/l Cu. This preliminary stripped organic phase was then contacted vigorously with the copper leach solution at various organic to aqueous (O / A) ratios for sufficient time to obtain equilibrium. The resulting equilibrated organic phases were analyzed by atomic absorption for copper and iron while the resulting equilibrium aqueous phases were

analyzed by atomic absorption for copper only. The results are given in Table 1 below.

TABLE 1

Approximate O / A ratio	Aqueous Phase g/l Cu	Organic Phase	
		g/l Cu	ppm Fe
10	0.17	1.98	1.0
5	0.20	2.56	3.2
2	0.42	4.27	3.1
1.5	0.53	4.99	2.6
1	0.90	6.61	2.1
0.5	2.24	9.40	1.7
0.2	4.30	11.51	1.1

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The isotherm data was inserted into the Cognis Corporation Isocalc computer program which predicts with great accuracy the results that can be obtained in a continuous copper solvent extraction plant provided correct mixer efficiencies for the extraction stages are used. For this Example 1, the following mixer efficiencies were used: 95% for extraction stage 2 and 92% for extraction stage 1 in the 2E, 2S circuit and 95% for extraction stage 3, 92% for extraction stage 2 and 89% for extraction stage one in the 3E, 1S circuit. These mixer efficiencies are consistent with mixer efficiencies that are obtained in the 2E, 2S circuit and which can be obtained in a 3E, 1S circuit of the invention in modern copper solvent extraction plants. The stripped organic values that were used in the Cognis Isocalc computer program were obtained by equilibrating the organic with an aqueous solution to give a copper stripped organic value that is representative for either one or two stripping stages depending on the particular circuit simulation. In this example two sets of stripping conditions were used. In the first set of results the barren stripping solution had 35 g/l Cu and 180 g/l sulfuric acid building to a pregnant strip solution of about 50 g/l Cu and 157 g/l sulfuric acid. In the second set of results the barren stripping solution had 35 g/l Cu

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and 150 g/l sulfuric acid building to a pregnant strip solution of about 50 g/l Cu and 127 g/l sulfuric acid. Simulated circuits were run with the computer program at various advance organic / aqueous (O / A) ratios to compare the results obtained with 3 extraction and 1 stripping stage verses the results obtained with 2 extraction and 2 stripping stages.

The results of the computer simulations are shown below in Table 2.

TABLE 2

Set	Staging	Strip Organic g/l Cu	Advance O / A extraction	Copper Recovery	Net Transfer g/l Cu / Vol %
1a	2E, 2S	1.42	1.0	95.0%	0.276
1b	2E, 2S	1.42	0.71	90.2%	0.369
1c	2E, 2S	1.42	0.63	86.8%	0.40
1d	3E, 1S	2.16	1.0	96.6%	0.28
1e	3E, 1S	2.16	0.63	90.7%	0.418
2a	2E, 2S	1.83	1.0	94.1%	0.273
2b	2E, 2S	1.83	0.76	90.2%	0.345
2c	2E, 2S	1.83	0.70	88.2%	0.366
2d	3E, 1S	2.84	1.0	95.2%	0.276
2e	3E, 1S	2.84	0.70	90.7%	0.376

As can be seen from this example a circuit having 3 extraction and 1 strip stage will result in higher copper recovery than a circuit having 2 extraction and 2 strip stages when the circuits are compared under exactly the same conditions. For example compare 1d (96.6% Cu recovery) with 1a (95.0% Cu recovery) and 1e (90.7% Cu recovery) with 1c (86.8% Cu recovery). Also compare 2d (95.2% Cu recovery) with 2a (94.1% Cu recovery) and 2e (90.7% Cu recovery) with 2c (88.2% Cu recovery). In addition note that the Net Transfer (g/l Cu / vol %) of the reagent is higher in the 3E, 1S staging than in the comparable 2E, 2S staging, showing that the reagent is used more efficiently in the 3E, 1S staging than in the 2E, 2S staging.

When taken in the context of large modern copper solvent extraction plants a 1% increase in copper recovery can add substantial revenue. For example consider a copper solvent extraction plant producing 100,000 tons of copper annually. An extra 1% recovery results in an additional 1,000 tons of copper which has a value of about US \$1.5 million at a copper price of US \$1500 ton. An additional 4% copper recovery adds US \$6 million in revenue.

A second aspect of the 3E, 1S stage configuration that is a favorable over the 2E, 2S stage configuration is enhanced copper over iron (Cu / Fe) selectivity. This can be noted by comparing the Cu / Fe transfer for the loaded organic for some of the 2E, 2S sets with the Cu / Fe transfer for the loaded organic for similar 3E, 1S sets. First the iron loading on the organic phase for each isotherm point is plotted against the copper loading for the same point. This gives a graph that can be used to find the iron loading of the organic phase for any copper loading of the same organic phase. For the sets in Table 2 the copper content of the loaded organic is obtained from the computer simulated circuit run and then the iron loading for that copper loaded organic can be obtained from the graph of iron loading against copper loading. This data for some of the sets in Table 2 is given in Table 3.

TABLE 3

Set	Staging	Advance O / A Extraction	Copper Recovery	Stripped Organic g/l Cu	Loaded Organic g/l Cu ppm Fe	Cu / Fe Selectivity
1a	2E, 2S	1.0	95.0%	1.42	7.46 1.98	3050
1c	2E, 2S	0.63	86.8%	1.42	10.18 1.50	5840
1d	3E, 1S	1.0	96.5%	2.16	8.30 1.85	3320
1e	3E, 1S	0.63	90.7%	2.16	11.32 1.17	7830
2a	2E, 2S	1.0	94.1%	1.83	7.81 1.95	3070
2c	2E, 2S	0.7	88.2%	1.83	9.84 1.60	5010
2d	3E, 1S	1.0	95.2%	2.84	8.89 1.80	3360
2e	3E, 1S	0.7	90.7%	2.84	11.08 1.25	6600

The Cu / Fe selectivity is calculated as follows. The copper transfer of the organic phase is divided by the iron loading of the loaded organic phase [(Loaded Organic Cu – Stripped Organic Cu) / Loaded Organic Fe]. The data in Table 3 shows that for any set of comparable conditions the 3E, 1S stage configuration shows better copper / iron (Cu / Fe) selectivity than the 2E, 2S stage configuration. For example compare set 1a with set 1d, set 1c with set 1e, set 2a with set 2d and set 2c with set 2e. The higher Cu / Fe selectivity of the 3E, 1S stage configuration over the 2E, 2S stage configuration provides an added advantage for the 3E, 1S staging configuration over the 2E, 2S configuration.

10 Example 2

In a manner similar to Example 1, Example 2 also compares a copper solvent extraction circuit having 2 extraction stages and 2 stripping stages (2E, 2S) with a copper solvent extraction circuit having 3 extraction stages and 1 strip stage (3E, 1S). In this case the copper content of the leach solution was 61.37 g/l Cu at a pH of 1.8. This leach solution is representative of a concentrate leach solution. Two extraction isotherms were generated, one with 32 volume % LIX 84-I in a hydrocarbon diluent and one with 32 volume % LIX 984N reagent in a hydrocarbon diluent. LIX 84-I is a copper solvent extraction reagent available from Cognis Corporation of Gulph Mills, Pennsylvania, whose active copper extractant is 5-nonyl-2-hydroxyacetophenone oxime at a concentration of 1.54 molar. LIX 984N is a copper solvent extraction reagent available from Cognis Corporation whose active extractants are 5-nonyl-2-hydroxyacetophenone oxime (0.77 molar) and 5-nonylsalicylaldoxime (0.88 molar). The respective organic solutions were contacted vigorously with the copper leach solution at various organic to aqueous (O / A) ratios for sufficient time to obtain

equilibrium. The resulting equilibrated organic phase and aqueous phases were analyzed by atomic absorption for copper. The results are set forth in Table 4 below.

TABLE 4

Approximate O / A ratio	32 V/V % LIX 84-I		32 V/V % LIX 984N	
	Aqueous g/l Cu	Organic g/l Cu	Aqueous g/l Cu	Organic g/l Cu
20	13.16	2.46	3.56	3.00
10	18.64	4.38	7.41	5.67
5	25.08	7.31	14.91	9.56
3	31.66	9.85	24.21	12.64
2	36.33	11.61	31.49	14.65
1	45.97	14.40	43.41	16.80
2/3	51.62	16.15	50.88	17.77
1/2	54.37	16.54	53.87	18.12
1/3	56.52	16.76	56.08	18.27

5 In a manner similar to that described in Example 1, the isotherm data for each reagent in Table 4 was inserted into the Cognis Isocalc computer modeling program to predict with good accuracy the copper recovery expected in a continuous copper solvent extraction circuit when using the respective reagents at 32 volume % to treat

10 the concentrate leach solution of this example. The following mixer efficiencies were used: 98% for extraction stage 2 and 95% for extraction stage 1 in the 2E, 2S circuits and 98% for extraction stage 3, 96% for extraction stage 2 and 95% for extraction stage one in the 3E, 1S circuits. These mixer efficiencies are consistent with mixer efficiencies that are obtained in the 2E, 2S circuit and which can be obtained in a 3E,

15 1S circuit of the invention in modern copper solvent extraction plants operating at temperatures of about 35°C which is the temperature at which concentrate leach solutions will enter the copper solvent extraction plant. The stripped organic values that were used in the computer modeled circuit for LIX 84-I are consistent with stripped organic values that are obtained in operating copper solvent extraction plants

20 when the barren strip solution has 30 g/l Cu and 168 g/l sulfuric acid and the pregnant strip solution has about 45 g/l Cu and 146 g/l sulfuric acid. The stripped organic

values that were used for LIX 984N are consistent with the stripped organic values that are obtained in a plant when the barren strip solution has 35 g/l Cu and 180 g/l acid and the pregnant strip solution has 45 g/l Cu and 165 g/l sulfuric acid.

The results of the computer simulations are shown below in Table 5.

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TABLE 5

Set	Reagent	Staging	Strip Organic g/l Cu	Advance O / A extraction	Copper Recovery	Net Transfer g/l Cu / Vol %
1a	LIX 84-I	2E, 2S	0.88	4.0	67.2%	0.321
1b	LIX 84-I	3E, 1S	1.33	3.2	67.3%	0.404
2a	LIX 984N	2E, 2S	3.61	4.63	80.0%	0.331
2b	LIX 984N	3E, 1S	4.73	4.09	80.0%	0.375

In sets 1a and 1b the objective was to obtain about 67% copper recovery. It can be noted that the organic flow rate needed to obtain the desired copper recovery with the 2E, 2S staging (set 1a) is about 25% greater than the flow rate needed to obtain the same copper recovery with set 1b (the 3E, 1S staging) $[(4.0 - 3.2) / 3.2 \times 100\%]$. This means that the mixer/settler tanks in a plant using the 2E, 2S staging would have to be 25% larger in size than the mixer/settler tanks in a plant using the 3E, 1S staging. Thus a plant with 2E, 2S staging would have a higher capital cost by about 25% which is quite significant. For example, the cost to install a mixer/settler tank is about US \$400 per square foot of settler area on a fully prepared site.

Considering that large modern copper solvent extraction plants might have settlers that are 90 feet long and 90 feet wide, a single mixer settler unit of this size would cost about US \$3.24 million without considering site preparation costs. If each mixer settler unit needed to be 25% larger the cost would be 4.05 million dollars per mixer settler unit giving a total increase in capital for the 2E, 2S stage configuration of US \$3.24 million over the 3E, 1S stage configuration.

If the site preparation costs are high, and they often are because of the location of copper plants, the savings for the smaller 3E, 1S plant will be even greater.

In sets 2a and 2b, the objective was to recover 80% of the copper. It can be seen that the organic flow needed to obtain 80% copper recovery with the 2E, 2S staging is about 13.2% greater than the organic flow needed to obtain 80% copper recovery with the 3E, 1S staging $[(4.63 - 4.09 / 4.09) \times 100\%]$. This means that the mixer/settler tanks in a plant with the 2E, 2S staging would need to be about 13.2% larger than the mixer/settler tanks needed for a plant with 3E, 1S staging. Again this would result in a significant capital savings for the 3E, 1S configuration.

In both set 1 and set 2 of this Example 2, the copper net transfer of the reagent is greater for the 3E, 1S staging over the comparable 2E, 2S staging. This shows that the reagent is used more effectively in a plant having 3E, 1S staging when compared to a plant having 2E, 2S staging.

Example 3

In a manner similar to Examples 1 and 2, this Example 3 compares a copper solvent extraction circuit having 2 extraction stages and 2 stripping stages (2E, 2S) with a copper solvent extraction circuit having 3 extraction and 1 strip stage (3E, 1S). In this example the copper content of the leach solution is 4.57 g/l Cu at a pH of 1.8. This leach solution is representative of heap leach solutions commonly found in copper heap leaching operations. An extraction isotherm was generated with a solution of 0.225 molar 5-nonyl-2-hydroxyacetophenone oxime in a hydrocarbon diluent. The respective organic solution was contacted vigorously with the copper leach solution at various organic to aqueous (O / A) ratios for sufficient time to obtain equilibrium.

The resulting equilibrated organic phases and aqueous phases were analyzed by atomic absorption for copper. The results are given in Table 6 below.

TABLE 6

Approximate O / A ratio	Aqueous Phase g/l Cu	Organic Phase g/l Cu
10	0.039	0.481
5	0.08	0.945
3	0.14	1.56
2	0.22	2.31
1.5	0.31	3.01
1	0.52	4.3
0.67	0.98	5.74
0.5	1.49	6.59
0.2	3.15	7.70

In a manner similar to that described in Examples 1 and 2 the isotherm data in Table 6 was inserted into the Cognis Isocalc computer modeling program to predict with good accuracy the copper recovery expected in a continuous copper solvent extraction circuit when using the organic solution of this example. The following mixer efficiencies were used: 94% for extraction stage 2 and 90% for extraction stage 1 in the 2E, 2S circuits and 95% for extraction stage 3, 91% for extraction stage 2 and 88% for extraction stage one in the 3E, 1S circuits. These mixer efficiencies are consistent with mixer efficiencies obtained for 2E, 2S circuits and which can be obtained in a 3E, 1S circuit in modern commercial copper solvent extraction plants using a reagent of this type operating at temperatures of about 22°C which is a common temperature for heap leach solutions entering a copper solvent extraction plant. The stripped organic values that were used in the computer modeling program are consistent with stripped organic values that are obtained in operating copper solvent extraction plants when the barren strip solution has 35 g/l Cu and 180 g/l acid and the pregnant strip solution has 50 g/l Cu and 157 g/l sulfuric acid.

The results of the computer simulation are shown in Table 7 below.

TABLE 7

Set	Reagent	Staging	Strip Organic g/l Cu	Advance O / A extraction	Copper Recover y	Net Transfer g/l Cu / Vol %
1a	LIX 84-I	2E, 2S	0.31	0.645	90.1%	0.437
1b	LIX 84-I	2E, 2S	0.31	0.85	95.0%	0.35
2a	LIX 84-I	3E, 1S	0.56	0.573	90.1%	0.49
2b	LIX 84-I	3E, 1S	0.56	0.64	95.1%	0.465

In sets 1a and 2a the objective was to obtain about 90% copper recovery. It should be noted that the organic flow rate needed to obtain the desired copper recovery with the 2E, 2S staging (set 1a) is about 12.5% greater than the flow rate needed to obtain the same copper recovery with set 2a (the 3E, 1S staging) $[(0.645 - 0.573) / 0.573 \times 100\%]$. This means that the reagent in the 3E, 1S stage configuration is about 12.5% more efficient than that same reagent in 2E, 2S stage configuration. The increased net transfer of the reagent in the 3E, 1S staging also shows that the reagent is more efficient with 3E, 1S staging when compared to the 2E, 2S staging.

In sets 1b and 2b the objective was to obtain about 95% copper recovery. It should be noted that the organic flow rate needed to obtain the desired copper recovery with the 2E, 2S staging (set 1a) is about 32.8% greater than the flow rate needed to obtain the same copper recovery with set 2a (the 3E, 1S staging) $[(0.85 - 0.64) / 0.64 \times 100\%]$. In this case the efficiency of the organic phase in the 3E, 1S stage configuration is about 32.8% greater than the efficiency of the same organic phase in a 2E, 2S stage configuration. The much higher net transfer of the reagent in set 2b compared to set 1b confirms the higher efficiency of the 3E, 1S stage configuration.

In a plant with 2 extraction stages and 2 strip stages, a design that has been used commonly in the past, running under the conditions of set 1a achieving 90.1%

copper recovery which is a copper recovery that is often the basis for the design of copper solvent extraction plants, a simple change in the piping of the plant to a 3E, 1S configuration would allow the plant to achieve 95.1% copper recovery with all other conditions being the same (set 2b).

5 Example 4

In a manner similar to the previous examples, this example compares a copper solvent extraction circuit having 2 extraction stages and 2 stripping stages (2E, 2S) with a copper solvent extraction circuit having 3 extraction and 1 strip stage (3E, 1S). In this Example 4 the leach solution has 5.97 g/l Cu, 2.7 g/l Fe at a pH of 2.0. The organic solution contained about 0.194 molar 5-nonyl-2-hydroxyacetophenone oxime, about 0.189 molar 5-nonylsalicylaldoxime and about 28.2 g/l of the equilibrium modifier dodecanone all in the hydrocarbon diluent SHELLSOL™ D70. The respective organic solution was contacted vigorously with the copper leach solution at various organic to aqueous (O / A) ratios for sufficient time to obtain equilibrium.

15 The resulting equilibrated organic phases were analyzed for copper and iron while the aqueous phases were analyzed for copper. Analysis was by atomic absorption. The results are given in Table 8 below.

TABLE 8

Approximate O / A ratio	Aqueous Phase g/l Cu	Organic Phase	
		g/l Cu	ppm Fe
1.5	0.21	4.25	---
1	0.42	6.11	8.6
2 / 3	1.00	8.31	4.6
0.5	1.70	9.51	3.2
1 / 3	2.87	10.52	2.6
0.25	3.62	10.97	2.5
1 / 6	4.41	11.28	2.6
1 / 8	4.78	11.51	2.8
1 / 10	5.03	11.55	3.0

In a manner similar to that described in Examples 1 – 3 above, the isotherm data in Table 8 was inserted into the Cognis Isocalc computer modeling program to predict with good accuracy the copper recovery expected in a continuous copper solvent extraction circuit when using the organic solution of this Example 4. The following mixer efficiencies were used: 94% for extraction stage 2 and 90% for extraction stage 1 in the 2E, 2S circuits and 95% for extraction stage 3, 91% for extraction stage 2 and 88% for extraction stage one in the 3E, 1S circuits. These mixer efficiencies are consistent with mixer efficiencies for 2E, 2S circuits and which can be obtained in a 3E, 1S circuit in modern copper solvent extraction plants using a reagent of this type operating at a temperature of about 22°C. The stripped organic values that were used in the computer modeled circuit are consistent with stripped organic values that are obtained in operating copper solvent extraction plants when the barren strip solution has 35 g/l Cu and 180 g/l acid and the pregnant strip solution has 50 g/l Cu and 157 g/l sulfuric acid. The results of the computer simulations are shown in Table 9.

TABLE 9

Set	Staging	Strip Organic g/l Cu	Advance O / A extraction	Copper Recovery	Net Transfer g/l Cu / Vol %
1a	2E, 2S	1.95	1.0	96.2%	0.267
1b	3E, 1S	2.57	1.0	97.7%	0.271
2a	2E, 2S	1.95	0.68	91.0%	0.372
2b	3E, 1S	2.57	0.68	94.9%	0.387

In sets 1a and 1b the objective was to predict the copper recovery for the respective stage configuration when the advance organic / aqueous (O / A) flow across extraction is 1.0. It should be noted that the circuit having a 3E, 1S stage

configuration achieves a higher copper recovery than the circuit having a 2E, 2S stage configuration.

In sets 2a and 2b the objective was to compare the 2E, 2S stage configuration with the 3E, 1S stage configuration when the advance O / A is set to achieve about 95% copper recovery in the 3E, 1S stage configuration. Note that under conditions where the 3E, 1S configuration achieves about 95% copper recovery the 2E, 2S stage configuration only achieves about 91% copper recovery, all other conditions being the same.

Now as in Example 1, compare the Cu / Fe selectivity for the 2E, 2S sets in Table 9 with the Cu / Fe selectivity for similar 3E, 1S sets in Table 9. As in Example 1, the iron loading in the organic phase for each isotherm point is plotted against the copper loading for the same point. The resulting graph was then used to obtain an iron loading for any copper loading of the organic phase. For the sets in Table 9, the loaded organic was obtained from the computer simulated circuit run and then the iron loading for that copper loaded organic was obtained from the graph of iron loading verses copper loading. This Cu / Fe selectivity data for the sets in Table 9 is given in Table 10 below.

TABLE 10

Set	Staging	Advance O / A Extraction	Copper Recovery	Stripped Organic g/l Cu	Loaded Organic g/l Cu ppm Fe	Cu / Fe Selectivity
1a	2E, 2S	1.0	96.2%	1.95	7.70 5.35	~1100
1b	3E, 1S	1.0	97.7%	2.57	8.40 4.35	~1300
2a	2E, 2S	0.68	91.0%	1.95	9.94 2.85	~2800
2b	3E, 1S	0.68	94.9%	2.57	10.90 2.50	~3300

As discussed in Example 1, Cu / Fe selectivity was calculated by dividing the copper transfer of the organic phase by the iron loading on the loaded organic phase

[(Loaded Organic Cu – Stripped Organic Cu) / Loaded Organic Fe]. The data in Table 10 shows that for comparable conditions the 3E, 1S stage configuration results in higher Cu / Fe selectivity than the 2E, 2S stage configuration. For example, compare set 1a with set 1b, and set 2a with set 2b. The higher Cu / Fe selectivity of the 3E, 1S stage configuration over the 2E, 2S stage configuration provides an added advantage of the 3E, 1S staging configuration over the 2E, 2S configuration.